

# 博士学位论文

## 锥光纤微球型光分插复用器和 光分插复用器组网应用

**Optical Add/Drop Multiplexer Based on Tapered  
Fibers–Microsphere Resonators and Optical Add/Drop  
Multiplexer's Application in Optical Networks**

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厦 门 大 学

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Fibers–Microsphere Resonators and Optical Add/Drop  
Multiplexer's Application in Optical Networks**

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## 摘 要

本文研究锥光纤微球谐振腔新型光分插复用器 (OADM) 和 OADM 在铁路链式通信传输网中的组网应用。

OADM 是全光通信网的核心器件之一,研究新型的 OADM 器件一直受到了很大关注。我们研究了基于锥光纤瞬逝波与微球腔回廊模耦合的锥光纤——微球谐振腔—锥光纤 (TRT) 结构的 OADM,它具有光纤兼容性、信道插入损耗小、消光大、耦合效率高、容易集成在硅片衬底上等优点,具有很高的性能价格比和广阔的应用前景。

根据电磁场理论分析了锥光纤瞬逝波与微球回廊模的耦合机理,得到了两者最佳耦合的匹配条件。以此为根据我们设计并用微机电(MEMS)工艺制作了集成于硅单晶衬底上的双微球三条锥光纤 TRT 新型 OADM。详细的测试和分析表明,它对单频可调谐激光有良好的分插功能、直通信道损耗小(约 0.3dB)、相邻信道隔离度较高。观察到了微球谐振腔的谐振吸收谱,窄的谱线反映出谐振腔具有高 Q 值 ( $4 \times 10^5$ )。根据形貌相关谐振谱线位置公式,对所测得的谐振吸收峰进行了识别指认,理论和实验符合良好。为了简化 TRT 型 OADM 器件制备工艺,提高器件的可靠性,提出锥光纤微盘型 OADM,并对其制备工艺作了初步探索,已在硅片上制成了  $\text{SiO}_2$  微盘和夹持光纤的 V 槽。以上工作未见国内外报道。本文提出了微球和长周期光纤光栅耦合的新型 OADM 的设想,对它的耦合条件作了初步分析。

针对铁路通信链式传输网的特点,本文提出了用 OADM 与 DWDM 组合扩容升级的新方案,并讨论了影响本方案网络规模的各种因素。用逻辑单星型实际的网络线路,模拟了福州——闽清铁路段通信网改造。传输实验测试表明本方案具有投资少、安全可靠、每个光节点接入一个波长、扩大传输容量等优点。本方案于 2003 年 3 月 5 日通过上海铁路局科委组织的通信专家鉴定,获得好评。

**关键词:** 光分插复用器; 锥光纤; 微球

## ABSTRACT

In this paper, we had studied a novel type of optical add/drop multiplexer(OADM) based on tapered fibers —microphere resonators ,and the application of OADM in the railway bus architecture communication network.

The OADMs are key elements in all optical fiber communication network , the research of novel OADMs has been receiving considerable attention.

We had studied the OADM of a Taper-Resonator-Taper (TRT) structure, based on the coupling between the evanescent wave of the fiber taper and the whispering gallery modes of the fused-silica microsphere. This kind of OADM exhibited outstanding advantages, such as high extinction ratio(>25dB),low insertion loss(~0.3dB),as well as intrinsic fiber-optic compatibility, ease of integration with silicon, opening up highly cost effectiveness and a broad application .

According to the theory of the electromagnetic fields ,we had analysed the principle of the resonance coupling between the evanescent wave of the fiber taper and the whispering gallery modes of the microsphere resonator , and had obtained the optimal match conditions of the coupling. In terms of the optimal coupling conditions, we had designed a novel OADM device composed of double microspheres and triple fiber tapers on silicon substrate . The device was fabricated by using the standard MEMS technology. After measured the device carefully ,it showed that low insertion loss(about 0.3dB) for the pass through channel , well add/drop function for the single mode tunable laser, high isolation for the adjacent channel .We had observed the resonance absorption spectrum of the microsphere resonator, narrow linewidth indicated the resonator to be high Q value( $4 \times 10^5$ ). We had recognized the resonance absorption spectrum according



to the position formula of morphological resonance frequencies. From the results , the theory was compatible with the experiment.

In order to simplify the fabrication technology of the TRT OADM device and to improve it's reliability ,we proposed a novel Taper-Microdisk Resonator-Taper OADM, and make some previous work such as : the  $\text{SiO}_2$  microdisk and the V-grooves used to clamp taper fiber on a silicon substrate were fabricated. Another new type of OADM was proposed , composed of long period fiber gratings (LPFG) and microsphere resonator. We had illustrated the coupling mechanism and condition in theoretical. As a potential application, we described a four-port passive Add/Drop device based on the LPFG- microsphere coupling.

Refer to the characteristics of the railway communication chain network of China , a novel scheme to enlarge the capacity of the communication network by using the device of OADM and DWDM was proposed, as well as the optical node architecture. The limitation factors of the network scale were discussed .We had demonstrated the logical single-star architecture network transmission performance simulated the actual communication section from Fuzhou to MingQing Railway station, the results of the experiment showed that the scheme has the advantages as follows : cost effectiveness, survivability, enlarge the transport capacity by accessing an optical wavelength for every station. The scheme had been passed the appraisal organized by the Science and Technology Committee of the Shanghai Railway Bureau , received approval from the experts in railway communication .

**Keywords:**Optical Add/Drop Multiplexer(OADM); Tapered fiber;  
Optical Microsphere.

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## 第一章 绪 言

### 1.1 光分插复用器是全光网络中的关键器件之一

随着国民经济的持续增长,信息交流的日益增多,社会对通信传输网建设的发展提出了更高的新要求。通信业务将不仅仅局限于传统的话音业务,在本世纪初,单一的话音业务将逐步过渡到话音、数据、多媒体的宽带综合业务。特别是近几年来,IP 业务在全球范围突飞猛进地发展,已经给话音业务造成巨大的冲击。以 IP 为承载体的数据业务、多媒体业务等是通信业务发展的新热点。现代企业对数据传输的需求成快速增长,未来企业为每台 PC(个人计算机)规划为 10Mb/s 的带宽,大的商业点将需要近 2.5Gb/s;个人用户对带宽的需求也以很高的速度在发展,随着 ADSL(不对称数据线路)、HFC(光纤同轴混合网)、无线、光纤等宽带接入技术的应用,高速因特网接入家庭已不是遥远的愿望,而将成为实实在在的现实。这些需求和发展首先对传输网络的带宽提出了相应的要求。

为增加传输网络带宽光波分复用(WDM)技术应运而生,并被认为是宽带信息传送网络的优选方案,是增加通信系统的容量以满足日益增长的业务需求的一种行之有效的技术。密集波分复用(DWDM)系统的引入既是网络升级扩容的有效手段,又是迈向透明的全光通信网的第一步。世界范围内各电信运营者均利用该技术进行点对点扩容以及进行光联网的建设。

随着 DWDM 技术、光放大技术和光交换技术的日益成熟和实用化,光子技术在通信网中的应用已经逐渐超出了点到点传输的范围,向网络的更高层渗透。目前实用化的波分复用传输系统信道总容量可达 80Gbit/s,而且已经有公司推出了 400 Gbit/s 的波分复用系统。在这种超高速传输的网络中,

如果网络节点处仍采用原有的设备,进行光/电/光的变换,以电信号处理信息的方式进行交换、插/分复用,就会受到所谓的“电子瓶颈”的限制,节点将变得庞大而复杂,超高速传输所带来的经济性将被昂贵的光-电和电-光转换费用所抵消。

光分插复用器(OADM)正是适应这一要求而产生的。在节点中它可以根据需要将网络中的某路(或某几路)信道下路到本地或将本地信号上载到网络中,从而在光域实现了对网络容量的分配与管理,即OADM在光域内实现了传统的SDH电分插复用器在时域内完成的功能。因为OADM不再是光—电—光转换,这不仅大大降低了成本,同时也克服了电子速率的限制;它以波长为操作对象,因此与信号的调制方式、业务种类、传输协议无关,增强了网络的透明性;同时,随着OADM技术的不断发展,网络的灵活性和可控性也在不断增强。OADM是全光网络的关键器件,它的发展成熟,必将极大地推动光通信向全光网络化的方向发展。

## 1.2 基于目前铁路传输网的改造升级的需要

当代社会是信息社会,企业只有在信息社会中充分利用信息资源,才能在激烈的市场竞争中取得优势。实现铁路运输管理现代化,信息化要先行。要实现铁路管理信息化,通信网络宽带化是关键环节。但是,根据铁路运输生产的实际需要和信息化建设的要求,目前铁路通信网的运营能力还远不能满足承载各种业务的需求,尤其是随着铁路运输管理信息系统(TMIS)、铁路客票发售和预订系统(PMIS)、调度管理信息系统(DMIS)、车辆管理信息系统(CMIS)(统称管理信息系统(MIS))和办公自动化发展所带来的需求,更对传输网形成压力。铁路信息化面临着前所未有的挑战和考验,铁路运输管理信息化带来的巨量信息对通信传输网技术和条件提出了更为迫切的需求。先进的网络体系是确保铁路信息系统联网运行成功的先决条件和基础。



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